

“Multidisciplinary Analysis & Optimization Generation 1 and Next Steps”

**Presented at the NASA Fundamental Aeronautics Program 2nd Annual Meeting
Atlanta, GA, October 2008**

The Multidisciplinary Analysis & Optimization Working Group (MDAO WG) of the Systems Analysis Design & Optimization (SAD&O) discipline in the Fundamental Aeronautics Program’s Subsonic Fixed Wing (SFW) project completed three major milestones during Fiscal Year (FY)08: “Requirements Definition” Milestone (1/31/08); “GEN 1 Integrated Multi-disciplinary Toolset” (Annual Performance Goal) (6/30/08); and “Define Architecture & Interfaces for Next Generation Open Source MDAO Framework” Milestone (9/30/08). Details of all three milestones are explained including documentation available, potential partner collaborations, and next steps in FY09.



Multidisciplinary Analysis & Optimization Generation 1 and Next Steps

Cynthia Gutierrez Naiman
Subsonic Fixed Wing Project

Fundamental Aeronautics Program

2nd Annual Meeting

Atlanta, GA

October 7-9, 2008



SFW System Level Metrics

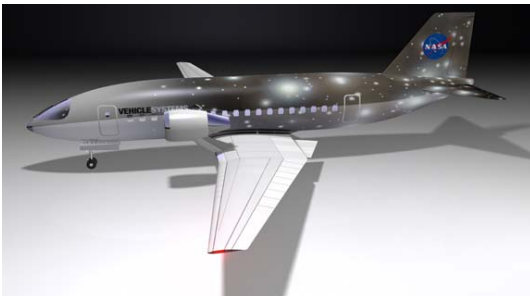
CORNERS OF THE TRADE SPACE	N+1 (2015 EIS) Generation Conventional Tube and Wing (relative to B737/CFM56)	N+2 (2020 IOC) Generation Unconventional Hybrid Wing Body (relative to B777/GE90)	N+3 (2030-2035 EIS) Generation Advanced Aircraft Concepts (relative to user defined reference)
Noise	- 32 dB (cum below Stage 4)	- 42 dB (cum below Stage 4)	55 LDN (dB) at average airport boundary
LTO NOx Emissions (below CAEP 6)	-60%	-75%	better than -75%
Performance: Aircraft Fuel Burn	-33% **	-40% **	better than -70%
Performance: Field Length	-33%	-50%	exploit metro-plex* concepts

** An additional reduction of 10 percent may be possible through improved operational capability

* Concepts that enable optimal use of runways at multiple airports within the metropolitan areas

EIS = Entry Into Service; IOC = Initial Operating Capability

N+1 Conventional



N+2 Hybrid Wing/Body



N+3 Generation





Topic Outline

- Background
- Organization
- Milestones
- Major Accomplishments
- Status & Plans
- Conclusion



Physics Based MDAO

- **National Need: Environment & Economy**
 - Unconventional configurations are essential to further reduce noise and emissions, while increasing performance.
 - PB MDAO is critical in designing & optimizing unconventional vehicles.
 - Industry needs advances in PB MDAO tools to design revolutionary vehicles in a cost-effective way.
- **Benefits include**
 - Enabling of unconventional design
 - Increased confidence in designs
 - Reduced technical risk, time to market, & cost
- **Gaps include**
 - Highly customized (and proprietary) to specific configurations and analysis processes
 - Configuration change necessitates rework
 - Lack of integrated variable fidelity capability



MDAO Working Group Organization

Fundamental Aeronautics Program Office
Director: Juan Alonso

**MDAO Integrated
Discipline Group**
Lead: Dean Kontinos

Subsonic Fixed Wing Project

Principal Investigator: Fay Collier

Project Scientist: Richard Wahls, **Project Manager:** Ruben Del Rosario, **Tech Integrator:** Anna McGowan

Acoustics API: Russell Thomas

Combustion API: Dan Bulzan

Aerodynamics API: Mike Rogers

Controls & Dynamics API: Diana Acosta

Aeroelasticity API: Jennifer Heeg

Materials & Structures API: Karen Taminger

Aerothermodynamics API: Jim Heidmann

SAD&O API: Bill Haller

SAD&O TWG

MDAO Working Group

Level 3 Lead
Steve Smith

Software Development Lead
Cynthia Naiman

Level 4 Lead
Craig Nickol

**Supersonic
Project**
API: Lori Ozoroski

**GEN1 Validation
Subteam**
Lead: Haller

**GEN2 HWB
Subteam**
Lead: Nickol

**OpenMDAO
Subteam**
Lead: Naiman

**Discipline,
Systems,
& MAO Experts**

**Computer
Scientists**

Support

Acoustics
Aeroelasticity
Combustion
Materials & Structures

Aerodynamics
Aerothermodynamics
Controls & Dynamics
SAD&O

Software Testing
Software Configuration
Management
Technical Writing
System Administration



MDAO Milestones

Title	End Date
Define Requirements for Integrated Design/Analysis Environment	1/2008

— Requirements defined applicable to all milestones



MDAO Milestones

Title	End Date
Define Requirements for Integrated Design/Analysis Environment	1/2008
Complete GEN 1 Integrated Multi-disciplinary Toolset	6/2008
GEN 1 Validation of Integrated Tool Set w/Experimental Data	12/2008

- Requirements defined applicable to all milestones
- GEN1 milestones



MDAO Milestones

Title	End Date
Define Requirements for Integrated Design/Analysis Environment	1/2008
Complete GEN 1 Integrated Multi-disciplinary Toolset	6/2008
GEN 1 Validation of Integrated Tool Set w/Experimental Data	12/2008
Complete GEN 2 Integrated Multi-disciplinary Toolset	6/2010
GEN 2 Validation of Integrated Tool Set w/Experimental Data	12/2010

— Requirements defined applicable to all milestones
— GEN1 milestones

— GEN2 milestones



MDAO Milestones

Title	End Date
Define Requirements for Integrated Design/Analysis Environment	1/2008 ★
Complete GEN 1 Integrated Multi-disciplinary Toolset	6/2008 ★
Define Architecture & Interfaces for Next Generation Open Source MDAO Framework	9/2008 ★
GEN 1 Validation of Integrated Tool Set w/Experimental Data	12/2008
Complete GEN 2 Integrated Multi-disciplinary Toolset	6/2010
Complete Alpha Release of Next Generation Open Source MDAO Framework	9/2010
GEN 2 Validation of Integrated Tool Set w/Experimental Data	12/2010
Demonstrate Next Generation Open Source MDAO Framework	9/2012

■ Requirements defined applicable to all milestones
■ GEN1 milestones

■ GEN2 milestones
■ Open Source milestones



FY08 Major Accomplishments

- Met **"Requirements Definition"** Milestone (1/31/08)
 - Completed:
 - *Vision & Scope Document*
 - *Use Case Document*
 - *Software Requirements Specification (424 functional & 23 non-functional)*
 - *Glossary*
 - *Requirements Prioritization*
- GEN1
 - Met **"GEN 1 Integrated Multi-disciplinary Toolset"** (Annual Performance Goal) (6/30/08)
 - *Completed Improvements to Codes & Integration Techniques: stability and control, noise, medium-fidelity aero prediction, high-lift aero prediction, and aircraft synthesis*
 - Verified Improvements Using Demonstration Cases: Ultra High Bypass Engine, DC9 Drag Polar, Supersonic Business Jet/Mixed Flow Turbofan
 - Completed *GEN 1 Integrated Multi-disciplinary Toolset SFW.01.01.009 Milestone Report* (6/30/08)
 - Hosted GEN1 Review Day (7/29/08)
 - Defined validation plan (conventional configuration)
- GEN2
 - Defined validation plan (conventional & unconventional configurations)
- OpenMDAO
 - Presented paper at AIAA MAO Conference: *AIAA-2008-6069 "The Development of an Open-Source Framework for Multidisciplinary Analysis and Optimization"* by Moore, Naylor, & Gray
 - Met **"Define Architecture & Interfaces for Next Generation Open Source MDAO Framework"** Milestone (9/30/08)
 - *Completed Next Generation Open Source MDAO Framework Architecture Document (9/30/08)*



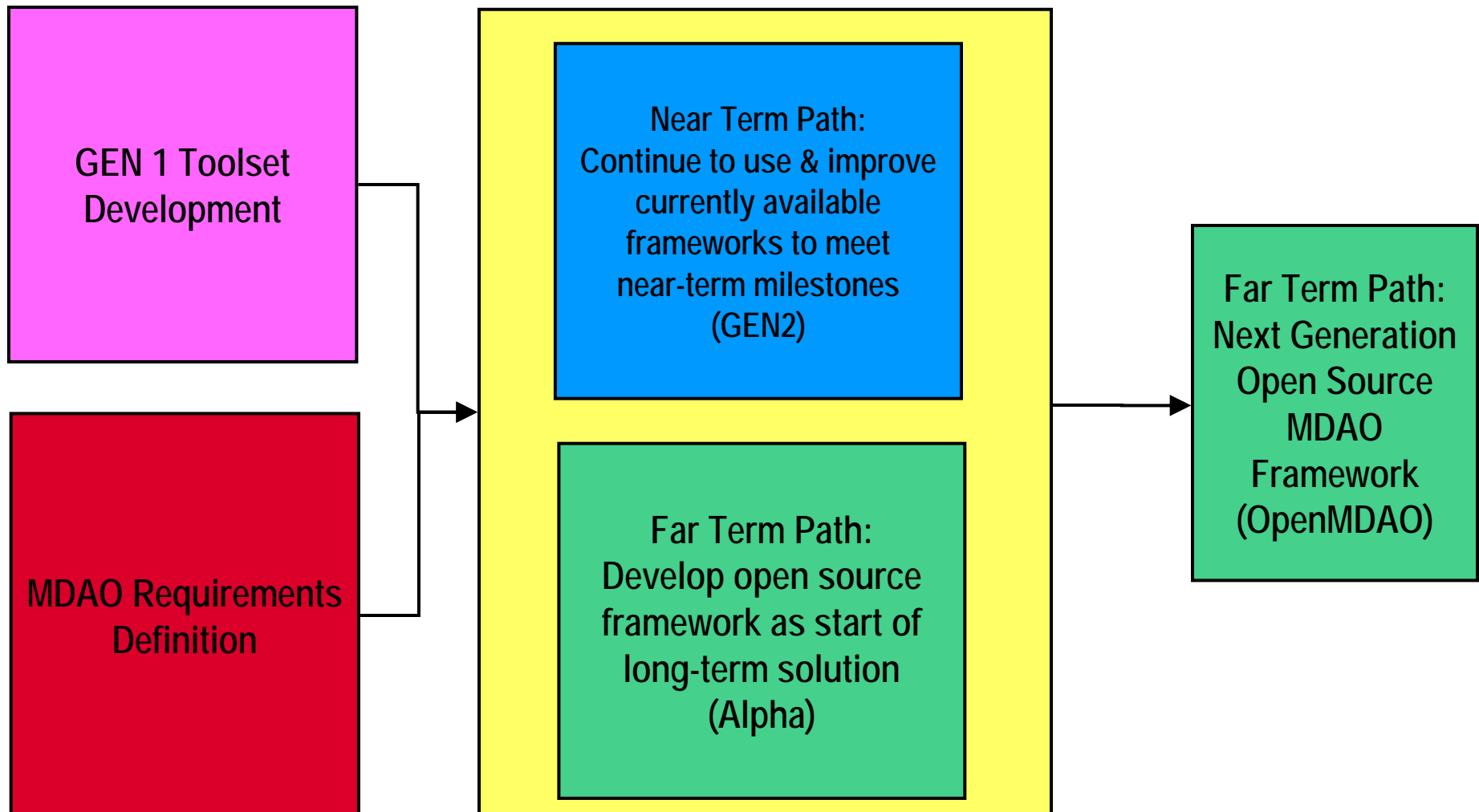
Decision Point: Parallel Path Approach

2008

Near Term Solutions

2010

Far Term Solutions 2012 & beyond





Why Open Source? *Components & Collaboration*

A framework is only as good as its components

- Open source → more users
 - More users → more component developers
 - More component developers → more components
 - More components → more functionality for users
-
- We can maximize the number of available components by making it easy to package a component and publish it on the web
 - Easier collaboration
 - No need to pay a price per seat to purchase the framework
 - Minimal red tape; just download it, install it, and go
 - Transparency -- Source code can be viewed by users
 - Researchers can see the algorithms
 - Many eyes find many bugs



Government Interest In Open Source Distribution

- NASA (*Outreach, Tech Transfer, Contributions back to NASA*)
 - NASA's Motivation for Open Source software distribution:
 - To increase NASA software quality via community peer review
 - To accelerate software development via community contributions
 - To maximize the awareness and impact of NASA research
 - To increase dissemination of NASA software in support of NASA's education mission
 - "Developing An Open Source Option for NASA Software" by Moran, TR NAS-03-009
 - NASA Open Source Agreement (NOSA)
- DoD
 - "Open Source Software (OSS) and the U.S. Department of Defense (DoD)" by Wheeler, 2/11/08, <http://www.dwheeler.com/oss-dod-webinar2008.html>



- GEN1
 - Prepare model to validate GEN1 (due 12/08)
- GEN2
 - Identify specific codes & integration improvements needed for HWB configuration
- OpenMDAO: OS framework does not require that components be OS
 - Pursue potential collaboration in OS MDAO community
 - Identify & define verification/validation test cases
 - Continue prototyping using python
 - Set up development environment & begin implementation
 - Follow process to classify framework as open source & publicly available
 - Follow up with industry, academia, & other government agencies
- Leverage NRA & SBIR MDAO efforts



- Completed 3 major milestones in FY08
- On schedule to meet future milestones
- 2-Path approach benefits near- and long-term needs
- Partnering with industry, academia, and other government agencies is essential to realize MDAO vision



Data on Requirements Development

Requirements Inspections

	Infrastructure 1	Infrastructure 2	Infrastructure 3	Infrastructure 4	Noise Tools	Geometry Tools	Mission Perf Tools	Uncertainty Tools	Emissions & Propulsion	Misc. Tools 1	Misc. Tools 2	Total
# of Reqs inspected	52	48	49	35	85	68	54	41	42	41	29	544
# of Defects Found	85	52	46	24	43	128	70	67	56	87	58	716
# of people attending inspections*	8	7	7	7	7	7	7	8	9	9	7	n/a
Hours in inspection meeting**	2.5	2.25	1.25	2	4	6	2.25	2	3	2.75	2.25	30.25
eRoom discussion forums***	2	2	2	5	6	9	6	0	1	6	2	41



Priorities for Functional Requirements

MDAO Framework Requirements

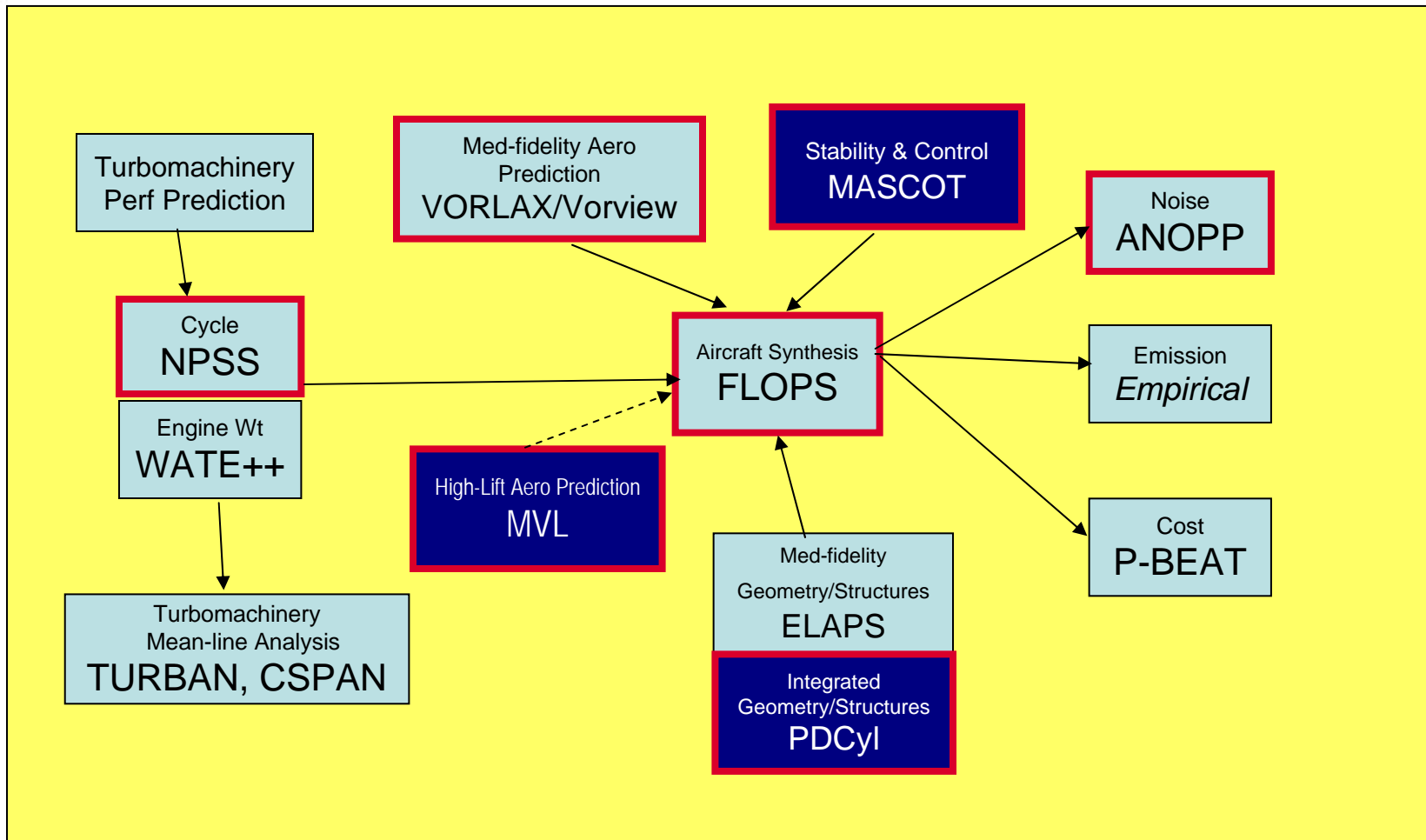
Category	Mandatory	High	Special Med.	Med	Low	Cat. Totals
Component Management	3	6	2	2		13
External Interface	1	7		7	6	21
Sim Configuration	4	6		3		13
Sim Data	1	3	1	2		7
Sim Execution	4	9	1	2		16
System Operations	2	4	3	1		10
Tool Coupling	5	4	1	3	8	21
Tool Wrapping	7	5	1	2	1	16
User Interface	13	21	7	14		55
Totals	40	65	16	36	15	172

MDAO Non-Framework Requirements

Category	Mandatory	High	Special Med.	Med	Low	Cat. Totals
Acoustics	13	24		14		51
Aerodynamics	2	12		1		15
Approximation	1	5	1	3		10
Cost	0	5		3		8
Design	5	6		3		14
Emissions	0	5		7	1	13
Geometry	12	11	9	6	3	41
Mission Perf	25	12		7		44
Optimization	0	11		1		12
Propulsion	7	7		9		23
Stability & Control	4	7	1	3		15
Structural Analysis	3	9		1		13
Take-off & Landing	6	2				8
Uncertainty	0	9		4	1	14
Totals	78	114	2	56	2	252



GEN 1 MDAO Framework Schematic



- Dark blue boxes indicate new capabilities over the GEN 0 Framework
- Red outline boxes identify tools discussed in further detail in GEN1 Milestone Report
- Solid arrows – integrated Dashed arrows – not integrated yet



OpenMDAO Architecture Document

- Top level context diagram
- Class diagram of most important classes, followed by descriptions of each class
- Sequence diagrams covering important areas, such as component execution and component creation
- A list of interfaces for system plug-ins (IComponent, IDriver, ICasewriter, IResourceAllocator,...)
- Important design decisions and reasoning behind them
- Deployment diagram for component publishing/downloading via egg servers
- Deployment diagram for a distributed model execution